Ekoloji 25, 98, 9-16 (2016)
doi: 10.5053/ekoloji.2015.23

Spatial Distributions of Heavy Metals in the Water and Sediments of Lake Çıldır, Turkey

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Abstract
In this study, the heavy metal levels were determined for the water and surface sediments of Lake Çıldır. The sediment particle size, organic carbon content, and pH were determined in the lake sediments in addition to the determination of the spatial distribution of heavy metals, as well as the metal enrichment levels for the sediment. The results of the metal analysis obtained using the Inductively Coupled Plasma Mass Spectrometry (ICP-MS) technique indicated that the metal levels in Lake Çıldır and spring waters which feed the lake were identified as Class 1 water quality according to the Turkish Surface Water Quality Regulation limits. Although the Ni and Cr levels found in the sediment were higher than some Sediment Quality Guideline (SQG) limits, the Ni and Cr levels of the core samples representing past periods provided no indication of enrichment for these elements. The spatial distribution of metals in Lake Çıldır was found to be affected by the depth, water inflows, outflows, and a derivation channel that has recently been built.
Keywords: Heavy metals, ICP-MS, Lake Çıldır, metal enrichment, sediment.

Çıldır Gölü (Türkiye) Su ve Sedimentlerinde Ağır Metallerin Alansal Dağılımları

Özet
Bu çalışmada Çıldır Gölünde su ve yüzey sedimentlerindeki ağır metal düzeyleri belirlenmiştir. Göl sedimentlerinde, ağır metallerin yanısıra tane boyu, organik karbon ve pH'ın alansal dağılımları ortaya konulmuş ayrıca sediment için metal zenginleşme düzeyleri tespit edilmiştir. İndüktif Eşleştirilmiş Plazma - Kütle Spektrometri (ICP-MS) tekniği kullanılarak gerçekleştirilen metal analiz sonuçlarına göre Çıldır Gölü ve gölü besleyen kaynak sularındaki metal düzeylerinin Yüzeysel Su Kalitesi Yönetmeliği (Türkiye) limitleri açısından 1. Sınıf su kalitesinde olduğu belirlenmiştir. Sedimentte tespit edilen nikel (Ni) ve krom (Cr) düzeyleri bazı Sediment Kalite Kriterleri (SQG) limitlerinin üzerinde olmasına rağmen geçmiş dönemleri temsil eden sediment karot örneklerine göre bu elementler için bir zenginleşme söz konusu değildir. Çıldır gölünde metallerin alansal dağılımında ise derinlik, su girdi, çıktıları ile yakın zamanda yapılmış olan derivasyon kanalının etkili olduğu belirlenmiştir.
Anahtar Kelimeler: Ağır metaller, Çıldır Gölü, ICP-MS, metal zenginleşmesi, sediment.

Alkan A, Gokcek C, Akbas U, Alkan N (2016) Spatial Distributions of Heavy Metals in the Water and Sediments of Lake Çıldır, Turkey. Ekoloji 25(98): 9-16.

INTRODUCTION

Lakes interact with three major components of a hydrological system, including atmospheric, surface, and groundwater (O'Sullivan and Reynolds 2003a). Chemical properties of lake waters are closely related to water inflows, outflows, and evaporation (Varekampa et al. 2000). Most pollutants are conveyed by rivers to the lakes and seas, but certain pollutants are conveyed by the atmosphere (O'Sullivan and Reynolds 2003a).

Heavy metals are resistant to degradation under natural conditions so they are the most persistent pollutants in the ecosystems (Suresh et al. 2012). Heavy metals reach lakes as a result of natural events such as erosion of rocks, volcanic activities, or anthropogenic activities such as mining, smelting, burning fossil fuels, and various industrial processes (Brönmark and Hansson 2005). Due to their low solubility in water, metals often accumulate in the sediment (Suresh et al. 2012).

Lake sediments are an important components of the ecosystems because they provide nutrients for living organisms (Suresh et al. 2012). The composition of lake sediments is affected by the

Received: 01.12.2013 / Accepted: 14.04.2015

geomorphology of the base and drainage basin, whereas, the chemical composition of the sediment is affected by both the lithogenic activities and the changes in climate and the drainage basin (Yıldız and Yener 2010). For this reason, one of the priority issues is to determine the contaminant levels in the sediment.

Volcanic lakes are significantly influenced by acid rain and metal pollution because they have low conductivity and a weak buffer capacity (O'Sullivan and Reynolds 2003b). Lake Çıldır, which is a volcanic set lake located within the provincial borders of Ardahan-Kars, is the largest freshwater lake of the Eastern Anatolia Region of Turkey. The aim of this study was to characterize the water and sediments of Lake Çıldır, clarify the sediment enrichment levels and identify the spatial distribution of heavy metals.

MATERIAL AND METHODS

Study Area

Lake Çıldır is located at 1959 meters above sea level, covers an area of 124 km^2, and the length and width of the lake is 18.3 km (north-south) and 16.2 km (east-west) respectively. Depending on the climatic conditions, the lake is usually covered by a layer of ice that is thicker than 60 to 70 cm during the winter. Although the lake has multiple inflows including Gölebakan (Yandere: 0.429 m^3/sec), Gölbelen (0.163 m^3/sec), Gülyüzü (Büyükçay), Dogruyol, Taşköprü and Lavaşin creeks, along with snow and rain water there is only one outflow, Telek Water (Fig. 1). Until recently, Lake Çıldır has been used for drinking water, but nowadays it is used for irrigation and energy production purposes.

Water and Sediment Sampling

The water and sediment samples were collected from 16 stations from Lake Çıldır (Fig. 1) in September 2011 and July 2013. Positions of sampling points were determined by GPS (Garmin Etrex, Taiwan) and sediment samples were taken using an Ekman grap (Hydrobios, Germany). Sediment core sampling was performed for the purpose of using it as background value during determination of the enrichment factor. The collected sediment samples were placed in plastic bags and taken to the laboratory with an ice cooled container.

Water samples were collected from the surface and bottom of the lake at the same 16 sampling stations using Nansen bottles (Hydrobios, Germany). Samples were filtered through 0.45 μm membrane filters before adding ultrapure HNO_3 and taken to the laboratory with an ice cooled container.

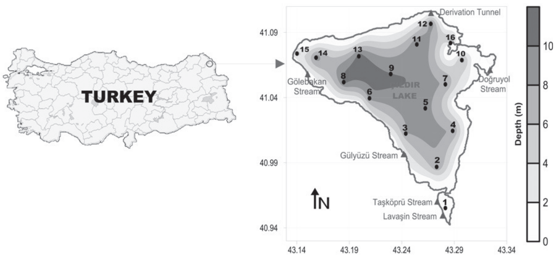

Fig. 1. Sediment and water sampling stations in Lake Çıldır.

In this study aluminium (Al), vanadium (V), chrome (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), molybdenum (Mo), cadmium (Cd), antimony (Sb), mercury (Hg), and lead (Pb) were found in the water samples and Al, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Cd, Ag, and Pb were detected in the sediments.

Particle Size Analysis of Sediments

Particle size analysis of sediments was performed according to the method of Udden (1914) and Wentworth (1922) using sieves with a pore diameter of 63 μm, 125 μm, 250 μm, 500 μm, 1 mm, and 2 mm (Retsch, Germany).

Analysis of Heavy Metals in the Water and Sediment

Sediments having a particle size below 63 microns were dried at 45°C. They were digested by using 6 mL of HNO_3, 1 mL of $HClO_4$, and 1 mL of H_2O_2 and a microwave digestion system and then completed to a volume of 25 mL with deionized water (Milestone 2011).

The heavy metal analysis was performed directly on the water samples and diluted sediment samples with a ICP-MS (Varian 820, Melbourne, Australia). Scandium (Sc), Indium (In), and Yttrium (Y) were used as the internal standards.

Other Chemical Analyses of the Sediment Samples

A total organic carbon analysis (TOC) was performed on the sediment samples sieved through a pore diameter of 500 μm using the modified method of Walkley and Black, (1934) and the carbonate determination was performed with the sediments sieved through a pore diameter of 2 mm with the method of Allison and Moodie (1965), the total phosphorus (TP) determination was performed titrimetrically using the method of Bray and Kurtz (1945), and the pH and electrical conductivity (EC) measurements were performed with the method of Kacar (1994).

Enrichment Factor (EF)

The determination of the Enrichment Factor in the sediment was calculated according to the method of Sutherland (2000) by applying Al normalization.

Enrichment Factor (EF)=[$(Me/Al)_{sample}$]/[$(Me/Al)_{background}$]

where the $(Me/Al)_{sample}$ is the Metal/ Aluminium ratio in the concerned samples and the (Me/Al)background is the natural background value of the Metal/Aluminium ratio. The means metal values belonging to the sediment below 30 cm taken from the core samples were used as natural background values.

Sediment quality classes were determined using the EF value. An EF<2 indicates a deficiency to low enrichment, 2<EF<5 is moderate enrichment, 5<EF<20 is a significant enrichment, 20<EF<40 is a very high enrichment, and EF>40 is an extremely high enrichment (Sutherland 2000).

RESULTS

The particle size composition of the sediments (a) and spatial distribution of the silt + clay (%) of the material at the stations (b) are given in Figure 2. The sediments of Lake Çıldır consisted of a sandy-muddy character in terms of particle size.

The mean, minimum, and maximum values of all measurements of Lake Çıldır and the spring waters and the Turkish Surface Water Quality Regulation limits (Quality Criteria of Intracratonic Surface Water Resources by their Classification) are given in Table 1 (Anonymous 2012). The mean values of the measurements (EC, pH, TP, $CaCO_3$, TOC, and heavy metals) of the surface sediments and some Sediment Quality Guidelines criteria in terms of the heavy metals are given in Table 2.

The phosphorus concentration, which is a very important and limiting element for eutrophication in fresh water ecosystem, ranged from 286.7 to 693.7 mg/kg in the lake sediments. Also pH, electrical conductivity (EC), total organic carbon and carbonate were measured as 7.16 - 7.40, 33.1 - 81.5 (μS/cm), 0.5 - 2.8(%), and 5.60 - 19.4(%) respectively.

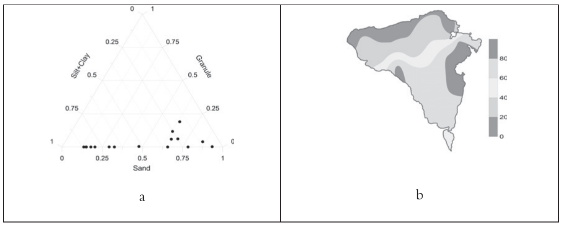

Fig. 2. Particle size composition of sediments (a) and spatial distribution of silt+clay (%) in Lake Çıldır.

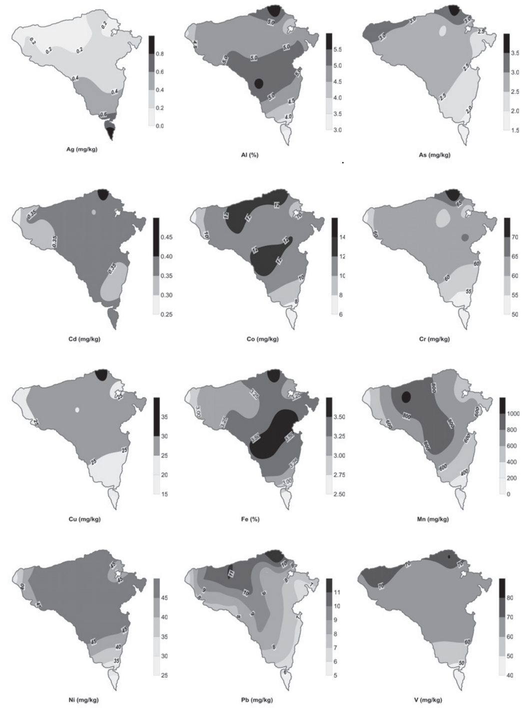

Fig. 3. Spatial distributions of Ag, Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and V in Lake Çıldır sediments.

The correlation coefficients among the parameters of the sediments are shown in Table 3. The spatial distribution of metals (Ag, Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and V) in the surface sediments are given in Figure 3. Zinc (Zn), pH, $CaCO_3$, and the TOC spatial distributions are given in Figure 4. The sediment metal concentrations were found to generally increase with depth and decrease with the direction of water flow. The fact that the TP spatial distribution in sediment was in line with the metals can be explained by the precipitation of metals with phosphates. The results of the factor loadings with a varimax rotation, the eigenvalues, and communalities are listed in Table 4.

Table 1. Water quality data of Lake Çıldır and streams water during of September (2011) and July (2013).

Parameter		Lake Water				Streams Water				Water Quality Class*			
	Unit	N	Mean±Std.Dev	Min	Max	N	Mean±Std.Dev	Min	Max	1	2	3	4
Temperature	(°C)	25	17.5±2.5	15.2	22.7	7	20.1±5.7	11.5	26.6				
pH		25	8.2±0.2	7.8	8.4	7	7.9±0.3	7.5	8.4	6.5-8.5	6.5-8.5	6.0-9.0	<6.0-9.0>
DO	(mg/L)	25	6.7±1.1	5.0	8.1	7	7.3±1.7	5.0	10.2	> 8	6-8	3-6	< 3
Al	(µg/L)	17	1812±151	1423	2000	2	33.1±13.2	23.8	42.4				
V	(µg/L)	8	3.3±0.2	3.1	3.8	5	1.9±0.9	1.3	3.6				
Cr	(µg/L)	25	1.3±1.1	<0.10	2.50	7	<0.10	<0.10	0.29				
Mn	(µg/L)	25	3.6±0.9	1.6	4.7	7	2.2±2.6	<0.10	7.1				
Fe	(µg/L)	17	855±66	686	934	2	159±120	74	244				
Co	(µg/L)	25	0.19±0.07	0.09	0.26	7	0.11±0.09	0.02	0.29				
Ni	(µg/L)	25	1.82±0.63	0.86	3.44	7	0.61±0.24	0.37	0.96	≤20	20-50	50-200	> 200
Cu	(µg/L)	25	2.07±0.81	0.48	3.50	7	0.98±0.91	0.26	2.36	≤20	20-50	50-200	> 200
Zn	(µg/L)	25	16.8±11.1	6.42	42.53	7	29.0±15.2	5.9	46.3	≤200	200-500	500-2000	> 2000
As	(µg/L)	25	1.6±0.23	1.16	1.82	7	0.85±1.08	0.16	3.25				
Mo	(µg/L)	25	0.67±0.2	0.35	0.82	7	-	<0.10	<0.10				
Cd	(µg/L)	25	-	<0.10	<0.10	7	0.24±0.14	0.11	0.48	≤ 2	2-5	5-7	> 7
Sb	(µg/L)	25	-	<0.10	0.12	7	-	<0.10	<0.10				
Hg	(µg/L)	17	0.014	0.010	0.020	7	-	<0.10	<0.10	< 0.1	0.1-0.5	0.5-2	> 2
Pb	(µg/L)	25	0.29±0.09	0.11	0.58	7	-	<0.10	<0.10	≤10	10-20	20-50	> 50

* Turkish Surface Water Quality Regulation limits (Quality Criteria of Intracratonic Surface Water Resources by their Classification).

Table 2. EC, pH, TP, $CaCO_3$, TOC and heavy metals concentrations of Lake Çıldır sediments and certain Sediment Quality Guidelines Criterias.

Parameter	Unit	N	Mean± Std.Dev.	Min	Max	TEL	MET	CBTEL	PEL	TET	CBPEL
EC	(mS/cm)	9	51.1±14.0	33.1	81.5						
pH		16	7.28±0.07	7.16	7.40						
TP	(ppm)	9	420±116	287	694						
$CaCO_3$	(%)	16	12.0±3.9	5.6	19.4						
TOC	(%)	16	2.2±0.6	0.5	2.8						
Al	(%)	16	4.8±0.7	3.3	5.9						
Fe	(%)	16	3.3±0.3	2.5	3.7						
V	(mg/kg)	16	65.1±8.3	41.2	80.6						
Cr	(mg/kg)	16	60.9±5.7	50.5	74.1	37.3	55	43.4	90	100	111
Mn	(mg/kg)	16	645±230	192	1067						
Co	(mg/kg)	16	10.8±2.0	6.4	13.5						
Ni	(mg/kg)	16	45.1±7.2	28.3	56.4	18	35	22.7	36	61	48.6
Cu	(mg/kg)	16	25.6±3.4	19.8	31.6	35.7	28	31.6	197	86	149
Zn	(mg/kg)	16	63.1±9.2	38.7	78.1	123	150	121	315	540	459
As	(mg/kg)	16	2.7±0.4	1.9	3.7	5.9	7	9.79	17	17	33.0
Ag	(mg/kg)	16	0.30±0.18	0.13	0.85						
Cd	(mg/kg)	16	0.36±0.04	0.26	0.41						
Pb	(mg/kg)	16	12.7±2.6	6.7	16.6	35	42	35.8	91.3	170	128

TEL: Threshold Effect Level MET: Minimal Effect Threshold PEL: Probable Effect Level
TET: Toxic Effect Threshold CBTEL: Consensus-Based TEC CBPEL: Consensus- Based PEC

DISCUSSION

The results of the measurements for Lake Çıldır and the spring waters feeding the lake were compared with the trace element limits in the Surface Water Quality Regulation and the water was found to have a class 1 water quality in terms of the trace elements (Ni, Cu, Zn, Cd, Hg, and Pb) reported in the regulation. A statistical difference of was determined between the lake and water resources feeding the lake in terms of temperature, DO, EC, Al, Cr, Mn, Co, Ni, As, Mo, Ag, Cd, Sb, and Pb concentrations $p<0.05$. However, the difference in pH, Cu, Zn, and Se concentrations were not significant ($p>0.05$). Temperature, EC, Al, Mn, Co, Ni, As, Mo, Ag, Sb, and Pb concentrations measured at the lake water stations were higher and

Table 3. Correlation matrix of surface sediments of Lake Çıldır .

	Depth	pH	EC	$CaCO_3$	TOC	Al	Fe	V	Cr	Mn	Co	Ni	Cu	Zn	As	Ag	Cd	Pb	Granule	Sand	Silt+Clay
Depth	1.00																				
pH	0.49	1.00																			
EC	-0.78	-0.51	1.00																		
$CaCO_3$	0.42	0.59	-0.42	1.00																	
TOC	-0.07	-0.35	0.41	0.04	1.00																
Al	0.76	0.21	-0.70	0.29	0.28	1.00															
Fe	0.70	0.14	-0.77	0.10	0.13	0.93	1.00														
V	0.88	0.41	-0.65	0.50	0.33	0.87	0.79	1.00													
Cr	0.70	0.46	-0.52	0.24	0.37	0.85	0.78	0.88	1.00												
Mn	0.74	0.41	-0.73	0.37	0.06	0.92	0.80	0.77	0.80	1.00											
Co	0.81	0.31	-0.69	0.31	0.27	0.98	0.90	0.91	0.91	0.93	1.00										
Ni	0.80	0.35	-0.68	0.39	0.32	0.97	0.88	0.95	0.92	0.91	0.99	1.00									
Cu	0.59	0.31	-0.54	0.37	0.43	0.90	0.78	0.83	0.90	0.88	0.93	0.94	1.00								
Zn	0.74	0.43	-0.68	0.45	0.31	0.94	0.85	0.91	0.93	0.90	0.95	0.97	0.93	1.00							
As	0.67	0.46	-0.68	0.21	0.03	0.83	0.76	0.72	0.84	0.90	0.89	0.85	0.88	0.81	1.00						
Ag	-0.89	-0.58	0.72	-0.57	-0.15	-0.76	-0.72	-0.96	-0.82	-0.70	-0.81	-0.86	-0.71	-0.85	-0.64	1.00					
Cd	-0.40	-0.10	0.07	-0.06	0.30	0.22	0.18	-0.11	0.20	0.25	0.16	0.15	0.40	0.25	0.28	0.24	1.00				
Pb	0.75	0.36	-0.79	0.40	0.11	0.95	0.87	0.82	0.82	0.98	0.95	0.95	0.91	0.93	0.88	-0.76	0.25	1.00			
Granule	0.43	0.56	0.03	0.22	-0.15	-0.09	-0.26	0.22	0.17	0.07	0.05	0.06	-0.05	0.01	0.11	-0.31	-0.64	-0.05	1.00		
Sand	-0.05	0.33	0.28	0.01	-0.43	-0.53	-0.65	-0.34	-0.33	-0.24	-0.41	-0.42	-0.44	-0.45	-0.22	0.21	-0.52	-0.38	0.81	1.00	
Silt+Clay	0.00	-0.36	-0.26	-0.03	0.41	0.49	0.62	0.29	0.29	0.21	0.37	0.38	0.41	0.42	0.19	-0.16	0.54	0.36	-0.84	-1.00	1.00

Table 4. Varimax rotated component loadings of factors and variance explained of Lake Çıldır sediments.

Parameter	Factor 1	Factor 2	Factor 3	Factor 4
Depth (m)	0.614283	-0.213201	0.612447	0.025749
pH	0.108668	-0.026196	0.825371	-0.079717
$CaCO_3$ (%)	0.348639	-0.454570	0.181245	0.643034
Organic C (%)	0.359414	0.689106	0.078653	0.485015
Al (%)	0.958878	0.173572	0.017380	0.150140
Fe (%)	0.872471	0.392768	0.020534	0.071765
V (mg/kg)	0.817310	-0.507253	0.009157	-0.134715
Cr (mg/kg)	0.870304	-0.118773	0.066581	0.373599
Mn (mg/kg)	0.665626	0.145611	0.656105	0.158700
Co (mg/kg)	0.899768	0.149171	0.321657	0.228151
Ni (mg/kg)	0.936737	0.088757	0.235718	0.227843
Cu (mg/kg)	0.905739	0.134848	0.095450	0.314129
Zn (mg/kg)	0.974421	-0.045890	0.046474	0.065652
As (mg/kg)	0.603083	-0.707269	-0.106521	0.048601
Ag (mg/kg)	-0.488806	0.613073	-0.345963	0.357799
Cd (mg/kg)	0.385855	0.325983	0.007124	0.814735
Pb (mg/kg)	0.940791	0.084437	0.169132	0.157120
Granule	-0.069840	-0.346379	0.779577	0.201097
Sand	-0.251562	-0.922839	0.131466	0.001949
Silt+Clay	0.243770	0.910597	-0.262409	-0.038318
Expl.Var	9.410129	4.045351	2.554952	1.934079
Prp.Totl	0.470506	0.202268	0.127748	0.096704
Eigenvalues	10.38	4.42	1.84	1.29
% Variance	51.9	22.1	9.2	6.5

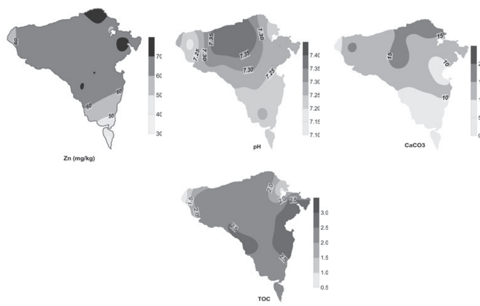

Fig. 4. Spatial distributions of Zn, pH, $CaCO_3$ (%) and TOC (%) in Lake Çıldır sediments.

Table 5. Comparing of the metal concentrations of Lake Çıldır sediment with some natural and Dam Lake sediments.

Sediment Sampling Location	Metals (mg/kg)							
	Cr	Mn	Co	Ni	Cu	Zn	As	Pb
Çıldır Lake (This study)	51,1±3,1	554±185	9,6±1,5	37,6±5,5	21,8±2,3	87,6±16,1	3,0±0,6	12,9±2,3
Kovada Lake	17,59	165,96	-	25,93	13,77	23,14	-	4,42
Tokat Lakes	-	232	-	55,4	8,2	38,9	-	7
Van Lake	110-420	-	-	-	70-760	-	-	5-62,82
Hazar Lake	17-79	85-625	24-48	38-130	10-64	46-210	-	<DL
Beyler Dam	19,41	346,14	-	13,21	17,47	39,68	-	5,62
Seyhan Dam	118,995	803,63	-	-	19,8	39,09	-	-
Atatürk Dam	-	73,6	-	-	14,57	60,79	-	-
Avşar Dam	14,48	-	-	29,99	29,98	-	-	2,44
Kıralkızı Dam	22,06	-	-	15,75	2,83	5,02	2,39	2,56
Batman Dam	16,5	-	-	15,96	nd	4,09	0,71	4,09

the dissolved oxygen (DO), Cr, and Cd concentrations were lower than those of the spring waters. The Ni concentrations in the deep waters of Lake Çıldır were higher while the DO concentrations were lower than the surface waters. The Ni and DO differences between the deep and surface water were statistically significant at the level of $p<0.05$. In terms of the minimum DO values measured in the waters of the lake as well as some spring waters were of Class 3 water quality during the summer.

When the particle size distributions of Lake Çıldır sediments were examined, it was seen that the large particle size of the sediments in stations 1 and 2 were similar those found in the stations at the outflow and inflow regions of the lake.

When the correlation tables for Lake Çıldır surface sediments were examined, a high degree of positive correlations between all metals, except for Ag and Cd were remarkable. Ag has a negative correlation with all metals. Although there was a high positive correlation between metals and depth, no significant correlation was identified with the pH, TOC, and carbonate.

There are many sediment quality guidelines approaches used to determine critical levels of pollutant in sediments for freshwater ecosystems (MacDonald et al. 2000). It was determined that the average Cr values in sediments were above the Threshold Effect Level (TEL) and Consensus-Based Sediment Quality Guideline (CBSQG) criteria and the average Ni values were above the TEL, the Minimal Effect Threshold (MET), and CBSQG, as well as the Probable Effect Level (PEL) criteria. It was observed that mean values of the other metals were below the critical values designated for ecological risk. The Ni concentrations detected in the sediment were above the other SQG's critical levels, other than Toxic Effect Threshold (TET) and CBSQG criteria. The Ni concentrations in the inflow waters of Lake Çıldır were low and the Ni concentrations in the deep waters of the lake were higher than that in the surface waters, suggesting that the Ni element was of lithogenic origin.

It was observed that average metal concentrations in the waters of Lake Çıldır were Al>Fe>Zn>Mn>V>Cu>Ni>As>Cr>Mo>Pb>Co>Sb>Cd>Hg in descending order. The average metal concentrations detected in the sediment were as Al>Fe>Mn>V>Zn>Cr>Ni>Cu>Pb>Co>As>Cd>Ag in descending order.

Baltacı, (2011) studied the accumulation levels of iron (Fe), copper (Cu), zinc (Zn), manganese (Mn), cadmium (Cd), and lead (Pb) metals in the muscle tissues of freshwater mussels, and in the sediments at the bottom of the lake and in the water. The heavy metals concentrations were found as Mn>Fe>Zn>Pb>Cu>Cd in theb water and Fe>Mn>Zn>Pb>Cu>Cd in the sediment.

The average metal concentrations in natural lakes and dam sediments in Turkey are given in Table 5. All metal concentrations in our study were higher than Kovada Lake (Kır et al. 2007), Beyler Dam Lake (Fındık and Turan 2012), Atatürk Dam Lake (Karadede and Ünlü 2000) and Kıralkızı and Batman Dam Lakes (Varol 2013).

Nickel (Ni) concentrations in Çıldır Lake sediments were found lower than in Tokat lakes (Mendil and Uluözlü 2007), copper (Cu) concentrations were lower than Avşar Dam Lake (Öztürk et al. 2009), chromium (Cr) and manganese (Mn) concentrations were lower than Seyhan Dam Lake sediments (Çevik et al. 2009).

Lead (Pb) concentrations determined in this study were higher than all the other lakes sediments except Van Lake. The mean zinc (Zn) concentrations determined in Lake Çıldır sediments were higher than the other lakes sediments except for maximum concentration in Hazar Lake (Ozmen et al. 2004).

Maximum concentrations of chromium, copper and lead measured in sediment core samples taken from the Van Lake, were higher than the values measured in this study (Yıldız and Yener 2010).

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Total organic carbon (TOC) in the lake sediments is closely associated with the productivity of the lake. The TOC concentration can also vary depending on the distance to the shore, particle size, sediment input, and carbonate concentration (O'Sullivan and Reynolds 2003c). The higher TOC values were detected in Lake Çıldır sediments from those areas close to stream inflows.

The maximum carbonate values in the sediment were obtained from the stations close to the derivation channel/tunnel, which can be attributed to the structure of the sediment conveyed to the lake via the derivation channel/tunnel. Research on the sediment carbonate concentrations may provide the basis for the estimation of the lake efficiency, and atmospheric CO_2 concentration in the past (O'Sullivan and Reynolds 2003c).

When the metal enrichment levels in Lake Çıldır sediments were evaluated, it was determined that the only Mn EF value (2.6) was in station 13 which was at a moderate enrichment level, whereas, the EF values of all the remaining metals were at a deficiency to low enrichment (<2) level. Although, particularly Ni and Cr concentrations in the sediment were higher than some SQG limits, the EF values for these metals was low and this can be considered as another evidence of the fact that these metals are of lithogenic origin.

Lastly, the results show that four eigenvalues explain 89.72% of the total variance. The first factor explains 51.9% of the total variance and loads heavily on Al, Fe, V, Cr, Mn, Co, Ni, Cu, Zn, and Pb. The second factor has a variance of 22.1% and loads mainly on a fine fraction (silt+clay) of the sediments and organic carbon. The other two factors were minimal which have variances of less than 17%. Considering this we may attribute these four factors 1, 2, 3, and 4 as lithogenic, grain size (fine fraction), redox potential, and anthropogenic/biogenic respectively.

ACKNOWLEDGEMENTS:

This work was partly supported by the Central Fisheries Research Institute. The authors also thank Bayram Zengin, Serkan Serdar, and Nihat Yazar for their help during the field surveys.

REFERENCES

Allison LE, Moodie CD (1965) Methods of Soil Analysis. American Society of Agronomy, Wisconsin.

Anonymous (2012) Surface Water Quality Regulation Ministry of Forestry and Water Affairs. Official Gazette of the Republic of Turkey Number: 28483, Ankara.

Baltacı BB (2011) Çıldır Gölü Suyunda, Dip Sedimentinde ve Buradan Çıkarılan Midyelerde (*Anadontacynea Linnaeus*, 1758) Bazı Ağır Metallerin Derişim Düzeylerinin Araştırılması. MSc Thesis, Kafkas University, Kars.

Bray RH, Kurtz LT (1945) Determination of Total, Organic and Available Forms of Phosphorus in Soils. Soil Science 59: 39-45.

Brönmark C, Hansson LA (2005) The Biology of Lakes and Ponds. Oxford University Press, NewYork.

Çevik F, Göksu MZL, Derici OB, Fındık O (2009) An assessment of metal pollution in surface sediments of Seyhan dam by using enrichment factor, geoaccumulation index and statistical analyses. Environmental Monitoring and Assessment 152: 309-317.

Findik O, Turan MA (2012) Metal concentrations in surface sediments of Beyler reservoir (Turkey). Bull Environ Contam Toxicol 88:193-197.

Kacar B (1994) Bitki ve Toprağın Kimyasal Analizleri: III, Toprak Analizleri. Ankara Üniversitesi Ziraat Fakültesi Eğitim Araştırma Geliştirme Vakfı Yayınları, Ankara.

Karadede H, Ünlü E (2000) Concentrations of some heavy metals in water, sediment and fish species from the Ataturk Dam Lake (Euphrates), Turkey. Chemosphere 41: 1371-1376.

Kır İ, Ozan ST, Tuncay Y (2007) Kovada gölü'nün su ve sedimentindeki bazı ağır öetallerin mevsimsel değişimi. Ege Journal of Fisheries and Aquatic Sciences 24: 155-158.

Mac Donald DD, Ingersoll CG, Berger TA (2000) Development and evaluation of consensus-based sediment quality quidelines for freshwater ecosystems. Archives of Environmental Contamination and Toxicology 39: 20-31.

Mendil D, Uluözlü ÖD (2007) Determination of trace metal levels in sediment and five fish species from lakes in Tokat, Turkey. Food Chemistry 101: 739-745.

Milestone (2011) SK-10 Application Book (Rev 5). Environmental Series Sorisole, HPR-EN-33, Sorisole.

O'Sullivan PE, Reynolds CS (2003a) The Lakes Handbook. In: Stumm W (ed), Limnology and Limnetic Ecology, Blackwell Science Ltd, Malden, 79-106.

O'Sullivan PE, Reynolds CS (2003b) The Lakes Handbook. In: Heinz L (ed), Limnology and Limnetic Ecology, Blackwell Science Ltd, Malden, 44.

O'Sullivan PE, Reynolds CS (2003c) The Lakes Handbook. In: Patrick O (ed), Limnology And Limnetic Ecology, Blackwell Science Ltd, Malden, 612-628.

Ozmen H, Kulahci F, Cukurovali A, Dogru M (2004) Concentrations of heavy metal and radioactivity in surface water and sediment of Hazar Lake (Elazig, Turkey). Chemosphere 55: 401-408.

Öztürk M, Özözen G, Minareci O, Minareci E (2009) Determınation of heavy metals in fish, water and sediments of Avsar Dam Lake In Turkey. Iranian Journal of Environmental Health Science and Engineering 6: 73-80.

Suresh G, Sutharsan P, Ramasamy V, Venkatachalapathy R (2012) Assessment of spatial distribution and potential ecological risk of the heavy metals in relation to granulometric contents of Veeranam lake sediments, India. Ecotoxicology and Environmental Safety 84: 117-124.

Sutherland RA (2000) Bed sediment-associated trace metals in an urban stream, Oahu, Hawaii. Environmental Geology 39: 611-627.

Udden JA (1914) Mechanical composition of clastic sediments. Geological Society of America Bulletin 25: 655-744.

Varekampa JC, Pasternackb GB, Rowe GL (2000) Volcanic lake systematics II, chemical constraints. Journal of Volcanology and Geothermal Research 97: 161-179.

Varol M (2013) Dissolved heavy metal concentrations of the Kralkizi, Dicle and Batman dam reservoirs in the Tigris River basin, Turkey. Chemosphere 93(6): 954-962.

Walkley A, Black LA (1934) An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the Chromic acid Titration method. Soil Science 37: 29-38.

Wentworth CK (1922) A scale of grade and class terms for clastic sediments. The Journal of Geology 30(5): 377-392.

Yıldız N, Yener G (2010) Dating of the Sediment Accumulation Rate, Radioactive and Heavy Metal Pollution in the Van Lake. Ekoloji 19(77): 80-87.